NATIONAL HYDROLOGY RESEARCH CENTRE

CENTRE NATIONAL DE RECHERCHE EN HYDROLOGIE

CANADA'S GREEN PLAN
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RESEARCH LEADERSHIP IN THE SCIENCE OF WATER

The National Hydrology Research Centre conducts research on issues relevant to the sound management of Canada's aquatic resources. These include the detection and prediction of climatic change, nutrients and toxics in surface and ground waters, environmental impacts on northern systems, and the integrity and health of aquatic ecosystems. In collaboration with national and international partners, NHRC scientists participate in interdisciplinary research programmes designed to address regional, national and international environmental problems.

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Hydrometeorological Processes Division

Report on Recent Activities

1992 - 93

The Hydrometeorological Processes Division is a component of the Atmospheric Environment Service's Climate Research Branch. Its primary goals are to understand and model climate processes occurring over a range of space and time scales and to understand the role of meteorological and climatic processes in the hydrological cycle. Together with the National Hydrology Research Institute, the Division conducts and manages research as part of the Canadian GEWEX program.

EVAPORATION STUDIES

Regional Evaporation Study

Evaporation studies are directed towards finding improved techniques for estimating evaporation and for scaling-up local measurements of areal estimates to scales that are useful for validating General Circulation Model (GCM) outputs. During the past year, work focused on the assimilation and quality control of data collected during the summer of 1991. The resultant archive will contain approximately 300 specially instrumented balloon soundings at Kenaston, Saskatoon, and Outlook yielding basic state thermodynamic and wind data at 15-minute intervals from 198 automatic weather stations, NOAA and GOES visible and infrared satellite data, Elbow radar (CAPPI) data, soil moisture and temperature data, and rain gauge information at 1-km intervals over the southeastern portion of the RES network. These detailed data sets cover an area of 100 km x 100 km south of Saskatoon. In addition, hourly synoptic data and radiosonde data from the North American continent have been added to the archive. The development of this data base has been very time consuming but it is being used extensively in this project and in other divisional projects.

In September 1992, the Division hosted a workshop on evaporation at which results from the Regional Evaporation Study were reviewed and linked to other work on evaporation being undertaken at the National Hydrology Research Centre and elsewhere. Participants also identified future work to advance prairie evaporation studies.

Wetland ecosystem vulnerability study (WEVS)

At the St. Denis wetland area in Saskatchewan, a special project to study problems in measuring humidity was conducted. Three data loggers were installed and instrumented over wheat, prairie grass and the wheat/grass interface during the summer of 1992. Differences of 15% in the relative humidity were found, due primarily to sensor errors. Since humidity measurements are critical in evaporation studies, closer scrutiny of the sensors must be a priority in future studies.

HYDROCLIMATOLOGY

CliRed

A project entitled "Climatological and Hydrologic Variability and Change in the Red River Basin" (CliRed) is being conducted jointly by the North Dakota District Office of the United States Geological Survey and the Hydroclimatology Section of the Hydrometeorological Processes Division. The Red River Basin drains 290,000 km^2 of the northern plains states and of Manitoba and Saskatchewan. Any significant change in the hydrologic regime in the Red River, caused either by climatic variability or long-term trends, could have significant effects on peak flows, volume, and the water quality of streams within the basin. The study has shown that low precipitation and streamflow events in the Red River sub-basins are associated with extended periods of a particular upper atmospheric circulation known as the positive phase of the Pacific-North America teleconnection pattern. This pattern comprises an upper atmospheric trough of low pressure over the Gulf of Alaska, a high

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pressure ridge over the western Canadian Prairies, and another trough over the eastern seaboard of the United States. The opposite pattern is correlated with high streamflow. The developing ability to forecast upper atmospheric patterns a month or more in advance should allow forecasting of the streamflow of the Red River.

Atmospheric moisture budgets

A cooperative project between Dalhousie University and the Division has been developed to estimate atmospheric water budgets as part of the Canadian contribution to GEWEX. The project attempts to diagnose important characteristics of the vertical and horizontal nature of water budgets, with a focus on the Mackenzie River basin, and to examine aspects of atmospheric water budgets that relate to precipitation efficiency, transport of moisture, latent heating profiles, precipitation/large-scale moisture convergence, and orographic lift. Initial work has concentrated on calculation of water vapour profiles from the standard radiosonde network across North America. A system using a Unix workstation and Anikon satellite meteorological information to estimate water vapour and its divergence over North America in near real-time has been developed at Dalhousie University. Future plans include installing the Dalhousie moisture analysis system at NHRC; using the Regional Evaporation Study's upper atmospheric data set from June-July 1991 to assess the utility of higher resolution radiosonde data for regional moisture analyses; adding observed precipitation rates; and adding the more numerous surface humidity and wind observations to the Dalhousie system.

Mackenzie hydroclimatological studies

A hydroclimatology for the Mackenzie River is being developed based on a combination of studies of meteorological and hydrologic conditions in the Basin for the period from 1973 to 1990. This work directly supports the MAGS (Mackenzie GEWEX Study) goal of developing a capability to predict the water balance of the Arctic drainage basin on space scales of 100 km and time scales of 1 month. The progress of breakup along the Mackenzie was documented and variations from year to year described. The compression of the breakup period as one moves northward along the Mackenzie has been documented although the mechanisms causing this compression are not yet fully understood. Uncertainties about the distribution of precipitation in the high water field portions of the Basin have led to a new project dealing with the development of distributed precipitation fields based on the use of the RHEA/CSU model.

Modelling precipitation extremes

Collaborative work with the National Hydrology Research Institute is in progress to analyze the implications of global climate model outputs for design statistics. The study will also provide some insights regarding the ability of the Canadian Climate Centre GCM II to simulate extreme daily precipitation amounts. Maps showing the maximum daily precipitation as simulated by the model are being compared to the actual precipitation extremes observed at different stations to determine the ability of the model to reproduce patterns of these extremes.

Inter-station precipitation correlations

Serial correlations between monthly precipitation anomalies have been analyzed for precipitation records from prairie climate stations with a view to determining how the interstation correlation patterns depend on geography, interannual variability (wet versus dry) and season. The results from this analysis may be of use in assessing the adequacy of existing observing networks to detect monthly anomalies and in contributing to our understanding of the relative importance of different precipitation processes in different seasons. A knowledge of these factors may also contribute to the development of techniques for distributing precipitation over a GCM grid square, particularly in zones of strong climatic gradients. Preliminary results of the analysis have shown that the average distance over which the correlations remain at significant levels (99%) is 300-500 km. This distance remains relatively constant between the seasons although the shapes of these high correlation areas change from summer to winter.

RADAR HYDROMETEOROLOGY

Weather radar assessment using a fine-scale surface network

A fine scale rain gauge network was operated in 1991 in the Kenaston area to help define the capability of the Elbow Radar system in resolving spatial patterns of rainfall. The analysis done in 1992 showed that the radar places the main part of the rainfall quite precisely on the map. Light rainfall and second-level parts of intense storms usually correspond to rain on the ground, but with very different values from those indicated by rain gauges. This spatial calibration will be used to estimate error limits on radar-derived precipitation maps.

Weather radar ground echo handling

Since weather radars scan near the horizon, their maps are often contaminated with ground echo. This old weather-radar problem was tackled by divisional staff using image-analysis techniques to define echoes, track them, and discriminate ground from rain on the maps. Techniques for the automated removal of ground echo, even in the presence of rain, were demonstrated using very simple data from a radar system that records only the intensity of echo for each point on the map. The new approach may be useful in weather forecasting as well as for research applications of weather radar.

Irrigation scheduling information system

The Division completed a project to demonstrate the use of radar rainfall maps in irrigation scheduling that involved the selection and application of a soil moisture model to determine irrigation needs. Radar rainfall maps were produced in an appropriate form and transmitted on request to the irrigation advisory office of Saskatchewan Water Corporation in Outlook, Saskatchewan. The product used most in this exercise was a weekly rainfall map of the region around Outlook published in weekly newspapers over the growing season in 1990. The final report is an assessment of the actual and potential use of radar data in this application.

Soil moisture workshop

The Hydrometeorological Processes Division together with NHRI's Hydrological Sciences Division hosted a Workshop on Soil Moisture Modelling and Monitoring at NHRC. This was the first national workshop on soil moisture since 1968, and was attended by participants from government labs in environment and agriculture, from research institutions in the United Kingdom and United States, as well as by university researchers in soils, hydrology and remote sensing. The proceedings, published in November, 1992, cover the needs for soil moisture modelling, the basic physics of soil moisture and of remote sensing, and the options available to modellers.

Environment Canada/United States Geological Survey meeting on projects of mutual interest

A meeting between seven scientists and managers of the United States Geological Survey and 31 scientists of Environment Canada was held on May 4-5, 1992 at the National Hydrology Research Centre. The meeting was intended to facilitate several water-related research and planning projects of mutual interest. Recommendations included increasing contact between the agencies through such means as scientific or managerial personnel exchanges, more meetings between scientists, and increased sharing of data.

CANADIAN GEWEX PROGRAM

Secretariat formed

At the end of September, Dr. Terry Krauss was appointed Head of the Canadian GEWEX Secretariat. He commenced work on October 1, 1992. Located at the National Hydrology Research Centre in Saskatoon, Dr. Krauss reports jointly to the Chiefs of the Hydrometeorological Processes Division of the Climate Research Branch and the Hydrological Sciences Division of the National Hydrology Research Institute. Dr. Krauss coordinates the implementation of Canada's contribution to the international GEWEX program including organizing scientific and planning meetings, informing the national and international science communities on the status of Canadian GEWEX activities, and coordinating the collection and dissemination of data from Canadian and relevant international GEWEX projects.

Canada's contribution to GEWEX

Significant progress was made in defining the scope and focus of the Canadian GEWEX Program during the year. A joint GEWEX Management and Science Committee meeting took place at Downsview, Ontario, October 14 and 15, 1992, followed by a two-day workshop to discuss the implementation plan of the Canadian GEWEX program. Key gaps in our present knowledge of high-latitude and cold-region physical processes and our ability to model them were identified and discussed. The central goal of the Canadian Mackenzie GEWEX Study (MAGS) is to develop the ability to model the water and energy balances of the Canadian Arctic Basin on spatial scales of 100 km and temporal scales of one month. Conceptual projects addressing physical processes and modelling of atmospheric and hydrologic processes and their linkages to climatic models were also discussed. Approximately 40 people, including more than 20 university researchers from eleven universities in five provinces, attended the GEWEX Planning Workshop.

GEWEX Continental-scale International Project (GCIP)

A Data Workshop hosted by the Hydrometeorological Processes Division was held at the National Hydrology Research Centre on May 5-8, 1992. The principal objectives of the workshop were to identify and promote action on practical problems and limitations related to the collection, quality assurance, archival and delivery of GCIP data: and to develop a data management system implementation plan. Thirty-six people from Canada and the United States participated in the workshop.

America's interhemispheric geobiosphere program (AMIGO)

The Divisional Chief organized and raised funds for the September 1992 AMIGO meeting in Victoria at which fifty scientists from a wide range of geophysical and biological disciplines from five countries in North and South America discussed how global change along the west coasts of North and South American will affect ecosystems. The Division prepared a report on transects of precipitation, temperature, cloud and radiation budgets along the west coast from 70° N to 55° S. Based on this transect, inferences were made about the impacts of hydrometeorological variables on biomass productivity and other biological indicators along the coast. A contract has been signed with Springer-Verlag to produce a book based on selected papers presented at the workshop.

Other activities

The Division provides support to the National Hydrology Research Centre by sharing in the funding of the Centre's image analysis and geographic information system as well as supporting research through the provision of scientific computing power using the Division's Hewlett Packard work station.

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The National Hydrology Research Centre conducts research on issues relevant to the sound management of Canada's aquatic resources. These include the detection and prediction of climatic change, nutrients and toxics in surface and ground waters, environmental impacts on northern systems, and the integrity and health of aquatic ecosystems. In collaboration with national and international partners, NHRC scientists participate in interdisciplinary research programmes designed to address regional, national and international environmental problems.

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Cold Regions Hydrology and Ecology

Report on Recent Activities

1992 - 93

Primary goal

- to sustain and enhance the integrity, biodiversity and productivity of northern aquatic ecosystems

Research studies in the Cold Regions Hydrology and Ecology Project are designed to generate a better understanding of hydrological, biophysical, chemical, and ecological processes in northern environments. At present, these processes are not well understood, making it difficult to make accurate assessments of the effects of resource development on fragile northern ecosystems. Researchers are studying the hydrological parameters that control water availability in cold regions, investigating the environmental effects of flow regulation/diversion and other resource developments on northern aquatic ecosystems, and developing models and systems to assess the effects of climatic change on these ecosystems.

Breakup and related environmental effects of river ice

From a river-aquatics perspective, river ice break-up can be the most significant event of the year in northern rivers. In severe cases, break-up is characterised by rapidly moving fronts that carry ice and water downstream at velocities in excess of 5 m s^{-1} and produce water levels that far exceed those which would occur under open-water conditions with equivalent discharge. Such dynamic processes are increasingly recognised as important modifiers of riverine environments. This is most apparent where flow regulation has resulted in a modification of the ice regime and produced significant changes in aquatic and riparian habitats. This research aims to quantify the environmental significance of break-up to cold-regions riverine ecosystems, and to develop the relevant environmental forecasting tools for predicting changes that could result from flow and ice-regime modifications.

In the summer of 1993, researchers from across Canada and the United States met at a workshop held at NHRI to discuss the present state of knowledge about the effects of river ice on aquatic ecosystems and to identify areas where research is needed. The meeting saw the release of a state-of-the-art report entitled *Environmental Aspects of River Ice* comprised of contributions on the subject under three main headings, physical, chemical and biological. A companion volume, the proceedings of the workshop, will be released in the near future.

Ice formation and related environmental effects

It is not only the break-up of river ice that can cause far-reaching environmental effects: ice formation, too, can have significant impacts, affecting, for example, the availability of water for hydropower generation. NHRI is currently studying the formation processes of different ice types and their effects. Phase 1 of an investigation of frazil and anchor ice under laboratory conditions is now complete and major findings have been published in a third progress report. The distribution of frazil ice in a flow was determined and an equation derived to fit the experimental data. Anchor ice was produced in the laboratory under controlled conditions. Phase 2 of the study is now well under way. A new experimental concept has been developed that will eliminate many undesirable effects, including centrifugal force. This study is a joint venture between NHRI and the National Water Research Institute in Burlington, Ontario with partial support coming from Ontario Hydro, Hydro Quebec, Manitoba Hydro, and New York Power.

Snowmelt runoff/chemistry in high latitude permafrost basins

In many areas of Canada, snow comprises over 50% of the annual precipitation, and its rapid melt in the spring often results in the largest runoff event of the year, with important implications for the health of ecosystems, water supply, and flood forecasting. Snow also plays a significant factor in the cycling of both nutrients and toxics. Unfortunately, there is little information on the magnitude of water or energy through cold-regions ecosystems, or the processes controlling them. This deficiency is partly due to our lack of understanding of snow processes in general, and of the unique aspects of cold snow/soil phenomena in particular.

Existing models have been developed for a narrow range of conditions typically found in temperate climates and are not, therefore, well suited for predicting snowmelt runoff in cold snowcovers. To develop robust models better suited to predicting snowmelt runoff from snowcovers under a range of climatic conditions, it is essential to conduct process/modelling studies at a range of sites spanning the entire north/south extent of the permafrost zone.

Field studies of snowmelt runoff are in progress at various northern research sites, including one tundra site near Inuvik, NWT, and analysis of data on snowmelt infiltration into frozen soils has begun. Work continues to develop and test models of water movement through cold snowpacks and to test the applicability of various techniques for measuring liquid water contents of melting snowpacks.

Snow atmosphere exchange: hydrology, chemistry, ecology

Snow is a major component of the hydrological cycle in Canada, dominating ecosystem integrity, biodiversity, and productivity in cold regions. An NHRI study is examining snow transport and sublimation processes, snow nutrient transformations during accumulation and metamorphic phases, toxic contaminant accumulation and transformation in snow, and the geochemical role of snowcovers. A major measurement session along the ecological transition between tundra and boreal forest, north of Inuvik has been completed. Blowing snow transport to the treeline was measured along with contaminants, trace elements,and nutrients carried by this snow. Sulphate loadings, which contribute to snow acidity, were found to be as high as in rural areas of southern Ontario, the culprit in the Arctic being the Arctic Haze aerosol which is picked up by blowing snow and deposited in forest snowdrifts along the edge of the tundra.

Measurements of snow accumulation and sublimation in Prince Albert National Park continue, as do comparison measurements of snow chemistry in differing boreal-forest stands. The chemistry of snow in spruce forests is much more acidic than that in aspen or open areas because snow intercepted by spruce branches collects atmospheric contaminants such as sulphate, which is then concentrated by sublimation of ice from the snow and, upon warming, is released to the ground. Snow accumulation measurements indicate that about 40% of the snowfall in dense spruce canopies sublimates before winter's end, compared to 5% in aspen canopies. Open areas small enough to limit blowing snow lose even less snow to sublimation. Information on snow accumulation produced by this study is available in a new NHRI Science Report entitled *Snow Accumulation, Relocation and Management.*

Transport of heavy metals in northern drainage systems

To investigate heavy metal attenuation processes in northern drainage systems, naturally acidic streams along the Dempster Highway, Yukon were examined and sampled in July. Analysis of these samples, augmented by the results of a previous study on natural acid rock drainage in the Macmillan Pass area, Yukon, enabled preliminary conclusions to be drawn with regard to the behaviour of a variety of chemicals in northern environments including As, Ba, Cd, Cr, Cu, Ni, Pb, Zn and V. Major mechanisms affecting the attenuation of these metals in northern drainage systems apparently include dilution, mixing, sorption, co-precipitation and efflorescence. The dominance of any individual mechanisms depends on the prevalent flow regime and is indirectly affected by temperature. Local vegetation, especially sphagnum, may enhance the attenuation process by physically trapping suspended particles. The role of boreal wetlands in attenuating heavy metal transport should be studied in more detail.

Permafrost wetlands: effects of climate change

The run-off regime of many northern rivers is dominated by the response of large wetland areas underlain by permafrost. The morphology of the permafrost is primary to the characterization of surface water capture, infiltration, and transmission. Such characterization not only aids experiments in global change detection, but improves the ability to model complex run-off regimes responsible for the generation of river ice break-up and jamming events. The goals of this study are to detect and assess the role of

climate variability on the spatial bounds and continuity of active-layer depth and permafrost features in a northern wetland basin within the discontinuous permafrost zone, and to assess the impact of global change on the wetland run-off regime in such a basin by adapting ground- and surface-water run-off models to accommodate the presence or gradual demise of complex subterranean hydrological divides. A methodology for the use of ground-penetrating impulse radar to detect the geometry and continuity of sub-surface permafrost structures has been developed, and modelling for the characterization of the snowmelt regime associated with the Manner's Creek Basin begun.

Mackenzie Delta hydrology and ecosystem interactions

The hydrologic regime of the approximately 25,000 lakes in the Mackenzie Delta is controlled by a complex interaction of processes occurring within each lake basin, factors controlling the discharge from the Mackenzie River basin, processes controlling ice-jam-induced spring floods in the delta, and sea level changes (both short and long term) in the Beaufort Sea. The relative importance of these processes and the spatial variations over the delta surface are not well known.

Important ecological characteristics of the lakes are determined by a combination of hydrologic and biogeochemical processes which are interactive and cannot, therefore, be studied independently. Only by understanding hydrologic and ecosystem processes, and developing the appropriate physically-based models, will it be feasible to predict the effects of various development scenarios, and/or global change (climate and sea level) on the lakes of the Mackenzie Delta.

An initial version of a model to predict changes in the lakes regime, given changes in main-channel water-levels, has been developed. Analyses of data demonstrating the impact of short-term changes in sea levels on channel levels in the Mackenzie Delta have been published. Current work includes collection of sediment cores from approximately 90 lakes for dating to determine total sedimentation between the early 1960s and the present.

INTERNATIONAL ACTIVITIES

Ninth International Northern Research Basins Symposium and Workshop

The National Hydrology Research Institute hosted the Ninth International Northern Research Basins Symposium and Workshop, an international meeting held biennially since the Working Group on Northern Research Basin (NRB) was established in 1975 to encourage "research on the hydrology of basins in northern latitudes where snow, ice and frozen ground play a dominant role." As part of the Ninth Meeting, scientists from Canada, the United States, the former U.S.S.R. and other circumpolar countries travelled between Whitehorse and Dawson via the icefields of the St. Elias Mountains and over the placer gold mining fields of the interior Yukon. From Dawson they proceeded to Eagle Plains and on through the Richardson Mountains to Inuvik, then over the Mackenzie Delta to the Beaufort Sea coast near the pingos at Tuktoyaktuk. The Symposium itself was held in Whitehorse and various workshops and field-work took place at different sites "on-the-road." NHRI organised the Meeting in this peripatetic way so that scientists from other countries had the opportunity to see the wide variety of Canada's cold-regions hydrologic regimes within a relatively short period of time.

The Symposium/Workshop was co-sponsored by a large number of agencies including Environment Canada, the Canadian Water Resources Association, the Department of Indian Affairs and Northern Development, and the Governments of the Northwest Territories and the Yukon. It had four general themes: monitoring hydrologic processes for climate-change detection, environmental effects of river ice, surface hydrologic database management and quality control, and energy-exchange instrumentation. A 1000-page, two-volume set of proceedings is now available.

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Climate and Glaciers

Report on Recent Activities
1992 - 93

Primary goals

- to obtain glacier mass-balance, hydrological, and meteorological data for use in detecting the impacts of climatic change on water resources
- to participate in national and international programs using glacier research to investigate global climatic change

The Climate and Glaciers Research Project comprises a set of studies designed to assist in the detection and assessment of the impacts of climatic change. A major focus of the project is the development of techniques to use glaciers as tools to detect impacts, particularly on water resources. Project scientists are also involved in research to develop hydrological models to assess the effects of climatic changes on the hydrological cycle. It is only with a thorough understanding of these effects that long-term sustainability of water resources can be safeguarded.

Glacier mass balance and detection of climate change

Since the mid-1900s most glaciers in western and north-western Canada have lost mass, presumably due to climatic and/or environmental change. Our ability to determine the full implications of the changing glacier cover and to predict future changes depends on exhaustive investigation of the nature and extent of these changes. With reference to four representative glaciers - Sentinel, Helm, Place and Peyto - the principal goal of this study is to obtain the various hydrological and meteorological data required for detecting change and for input into hydrological models to assess impacts.

Field programs have been successfully carried out on these glaciers and data from Helm and Place reduced and transmitted to the World Glacier Monitoring Service for the biennial publication "Glacier Mass Balance Bulletin." A start was made on optimizing the data-collection phase through the successful testing of a long-term accumulation/ablation monitoring tower at Place Glacier and the installation of cables in several ice tongues. One field experiment assessed the magnitude response of C-band Synthetic Aperture Radar (SAR) returns to snow-grain size for dry alpine snow covers; another examined surface roughness registration and calibration procedures for alpine targets during mid-winter. Experiments are now under way to use remote-sensing, index sites for ground-truthing, and remote, long-term instrumentation for essential field data acquisition. Data attained from this research is contributed to international programs such as the Global Energy and Water Cycle Experiment (GEWEX) and the CRYospheric SYStem to monitor global change in Canada (CRYSYS).

Development of a glacier component for distributed runoff models

The study aims to prepare a glacier component for NHRI hydrological models that can simulate watershed responses to variable climatic conditions. Glaciers are an extremely important hydrological component in many northern and mountainous basins because of their large storage capacities and their ability to influence streamflow regimes. The importance of each process for modelling runoff variations depends primarily upon the dynamics, bedrock topography and thermal regime of the glacier. There are a variety of simplifications that can be made to formulate a reliable glacier component for a basin-wide hydrological model. They require a better understanding of the glacier system itself and of ways to integrate the most important glacier-related processes into a physically-based conceptual model of a particular glacierized basin. Work is

in progress to develop a simple model of a glacierized basin that accurately represents the glacier system and optimizes the information available from remote sensing and mass-balance measurements. The data base to support this comes from Place Glacier where glacier mass-balance measurements have been carried out for a number of years and NHRI operates a weir. Radar-remote-sensing data and LANDSAT data have already been compiled for the area, but not yet analyzed in detail. A limited area digital elevation model (DEM) is available based on the 1965 1:10,000 map, and plans for acquisition of additional maps have been made.

Canadian Glacier Information Centre

The ultimate objective of this project is to provide the documentation on Canada's 100,000 glaciers required for assessment of climatic change, for input to State-of-the-Environment reports, and for contribution to national and international agencies. Excellent progress has been made on consolidating some of the historical information on snow and ice research in Canada. Individual bibliographies from 1975 through to 1992 were compiled into a master file that now contains more than 29,000 records. Although the principal focus is Canadian glaciers, with a subset of international references to rock glaciers, other Canadian work dealing with floating ice, snow and permafrost is also included. Records from the Yukon and Axel Heiberg Island glacier inventories are being converted into a Geographical Information System (GIS) using MapInfo®. It will be possible for the user to move through several levels of information, starting with the broad basin outlines for Canada, through the smaller hydrological basins and glacier numbers, to detailed data on each individual glacier. Index maps can be generated for particular areas of interest.

CRYSYS - The Yukon Glacier Inventory

NHRI glacier-research projects contribute to the Canadian CRYSYS (CRYospheric SYStem to monitor global change in Canada) program, which forms part of NASA's Earth Observing System. One such project, an inventory of Yukon glaciers, is virtually complete. Data conform to world glacier-inventory standards and consist of individual location co-ordinates, orientation, elevations and range, length, width, area, depth and volume estimates. They include a classification scheme that characterizes the shape and form of a glacier as well as its frontal characteristics and assumed activity. The data are organized within GLADYS (GLAcier Data-base inventorY System) which provides for ready access using a PC as well as within MapInfo®.

This inventory provides a comprehensive baseline for assessing regional changes. The two previous values used for the ice-covered area of this region are those of Flint and Henoch: 12,060 km for the Yukon Territory and District of Mackenzie, and 10,564 km for the Canadian drainage of the Yukon River. The ice-covered areas now available for comparison, albeit with the inventory still incomplete, are 13,170 km and 11,150 km - a reflection of the increased accuracy of the NHRI inventory rather than an expansion of the glaciers. When the inventory is complete, it is expected that the glacierized area of this region will have to be revised upwards by about 20%.

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Global Energy and Water Cycle Experiment (GEWEX)

Report on Recent Activities

1992-93

Primary goals

NHRI's GEWEX Project forms part of the Canadian GEWEX Program, a component of the international Global Energy and Water Cycle Experiment. Key objectives of this Experiment are to measure and model the hydrological cycle in order to predict more accurately variations in global and regional water resources and their response to environmental change. The Canadian GEWEX Programme contributes to the international effort in areas of Canadian interest and expertise, focusing on the effects of climatic changes on Canadian water resources particularly in colder, high-latitude regions. A central goal of Canadian GEWEX is to develop the ability to model the water and energy balance of the Canadian Arctic Basin. The geographic focus of this work is the Mackenzie River Basin. Studies in the NHRI Gewex Project form an integrated research effort directed toward gaining a better understanding of cold-regions hydrologic processes and improving parameterization schemes, developing remote sensing techniques, and using research results to develop models adaptable to the range of environments found in the Mackenzie River Basin.

PROCESS AND RESEARCH BASIN MODELLING

Biome-scale representation of snowcover development in boreal and tundra ecosystems

This study contributes to GEWEX objectives by providing a fundamental delineation of the cold-regions hydrological processes related to winter precipitation. The processes under investigation are snow accumulation, sublimation, and metamorphism: that is, the critical defining aspects of water cycling in boreal and tundra ecosystems. Field studies are in progress near Waskesiu, Saskatchewan in the southern boreal forest, and near Inuvik, NWT in the boreal/arctic fringe. Research is centred on snowfall/redistribution, snow interception, surface snow accumulation, atmospheric turbulent transfer, water vapour, heat transfer, and radiation exchange. Based on the data gathered in the field programme, algorithms of snowcover development will be derived for use in complex surface/atmosphere mesoscale models representing snowcover development and interaction with large-scale atmospheric conditions.

Runoff in boreal and tundra ecosystems

In boreal and tundra ecosystems, precipitation accumulates on the ground as snow for 6 to 9 months of the year and the bulk of annual runoff occurs over a brief 2 to 4 week period in the spring: surface energy fluxes are greatly affected by the underlying permafrost and changing snowcover, and the low permeability permafrost keeps most water near the ground surface. To gain a better understanding of runoff processes in these ecosystems, this study is investigating snowpack energy balance including soil heat flux over a variety of terrain and vegetation types: snow distribution: water flux through snowcover: snowmelt source areas: and the relative importance of various pathways between the source areas and stream channel, as well as their spatial and temporal variations. Results from this research will be used to develop physically-based parameterization routines for inclusion in hydrological models to be used at a variety of spatial and temporal scales.

Hydrologic response of lower Mackenzie systems in the discontinuous permafrost/wetland zone

In the discontinuous permafrost/wetland zone of the Mackenzie River basin, climatic change may lead to a lowering of hydrologic divides created by permafrost-cored sand ridges and, consequently, to alteration of the entire wetland regime and river response. The greatest impacts may be subsurface draining of ponded water, increases in long-term ground-water flow, reductions in surface runoff, and significant modification of the spring ice-flood wave. To assess the extent of these effects on the hydrologic

characteristics of this area, NHRI scientists are developing a distributed-hydrologic model of this wetland regime, specifically relevant to the spring snowmelt period and the near-surface, permafrost-melt periods. A field programme has been designed to collect landscape-hydrologic data along a transect of representative vegetation-terrain types. The model will be applied to a range of catchments of varying size along the Liard River.

REMOTE SENSING STUDIES

Parameterization of evapotranspiration using remotely-sensed data

In assessing the effects of climatic change on water resources in cold high-latitude regions, the correct evaluation of the role played by evapotranspiration is crucial. As data for these regions are often inadequate, remote sensing can be an effective tool in gathering the information required for developing models for cold-regions hydrologic processes. However, there are drawbacks to current methodologies for estimating evapotranspiration using remotely-sensed data; moreover, these methodologies are incompatible with approaches used in current General Circulation Models. The aim of this study is to verify a new evaporation model using remotely-sensed data for application in northern regions where the effects of changes in soil heat storage on the regional energy balance must be taken into account. At present, research is in progress at two sites: a tundra energy balance site near Inuvik, NWT and a low-latitude boreal forest site in Prince Albert National Park, Saskatchewan. A third site, in high-latitude open forest, will be added in 1994. Results of this study should facilitate improved estimation of regional evapotranspiration for areas such as the Mackenzie Basin, a core geographical area identified in the Canadian GEWEX Science Plan.

Radar satellite study of snowmelt and soil moisture in Mackenzie Basin target areas.

The Mackenzie River Basin comprises runoff from mountain, forest, and tundra areas. To enhance the capability of monitoring spring runoff in northern basins, thereby contributing to the research effort to model water and energy balances in the Mackenzie watershed, a satellite radar algorithm for high-resolution measurement of snowmelt detection is being developed. Project scientists are comparing C-band and L-band RADAR images of test sites with field data to test the sensitivity of RADAR observations from space to snowmelt, soil moisture and snow water equivalent. The objectives of this study are to derive algorithms for snowmelt detection in mountains, boreal forest, and tundra: antecedent fall and subsequent spring ground-moisture conditions in boreal forest and tundra: and snow water equivalent in mountains.

MACROSCALE MODELLING

Hydrological modelling within the Mackenzie Basin

Many processes within the hydrologic cycle are not well understood. This is particularly true of cold-regions processes such as the interaction of surface water with permafrost or the actions of glaciers as reservoirs. Moreover, data are generally sparser for cold-regions than for lower latitudes. The result has been that hydrologic models developed for temperate regions are not readily applicable to cold regions, and a critical need has emerged for the development of components for such hydrologic processes as cold snowcover, permafrost, and icecaps/glaciers. Focusing on the distribution and physical properties of snowcover, energy fluxes between soil layers and their effects on permafrost, and the behaviours of glaciated basins in releasing and storing water, this study is designed to contribute to the development of continental-scale hydrological models by providing cold-regions specific components presently absent.

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Nutrients/ Contaminants in Surface Waters

Report on Recent Activities

1992-93

Primary goal

- To preserve and enhance the integrity, biodiversity and productivity of aquatic ecosystems for future sustainability and environmental health

Scientists in the Nutrients/Contaminants in Surface Waters Project conduct research on lake and river ecosystems at locations in western and northern Canada. Studies focus particularly on the impacts of nutrients and contaminants on aquatic resources in these regions, and on the development of techniques for restoration. Project members also collaborate with scientists from other countries in international research projects on ecological issues. Details of research results and recent activities are given for each study in the Project.

Developing nutrient loading guidelines to protect river ecosystems

In Canada and other industrialized nations, heavy demands are placed on rivers as a source of water for domestic, agricultural and industrial purposes and as receiving water for domestic and waste-water effluents. The increase in nutrient loading from municipal, industrial (e.g. pulp mills) and agricultural sources during the past 30 years has caused many rivers throughout the world to become choked with submerged aquatic plants that block the flow of water (of particular economic significance in irrigation canals), impair recreational activities, cause fish kills, and modify aquatic habitats. During the past year, NHRI undertook research to quantify the impact of nutrient loading on the growth of submerged aquatic plants in rivers and to determine the role of these plants in nutrient transfer.

In collaboration with British Columbia Environment, Lands and Parks, work focused on the potential impacts of river regulation and nutrient loading on the abundance and distribution of submerged aquatic plants in the Nechako River. In association with Saskatchewan Environment, the City of Saskatoon and the Water Quality Branch of Environment Canada, Western and Northern Region, studies were initiated to assess the impact of advanced phosphorus removal at the Saskatoon sewage treatment plant on water quality and aquatic plant growth, and to evaluate the need for further upgrades at the sewage treatment plant. As well as this research, the effectiveness of a new non-toxic treatment for aquatic weed control (lime application) was tested in lakes, drinking-water dugouts and irrigation canals in cooperation with the University of Alberta, Alberta Agriculture and irrigation authorities in Alberta.

Results from this research programme will be used to develop nutrient and flow guidelines for rivers, facilitate the management of irrigation networks for sustainable agriculture, and develop techniques for the restoration of degraded lakes and rivers.

Effluent impacts on secondary producers in river ecosystems

Sustainable development of river ecosystems is threatened by environmental stresses from municipal sewage effluents and a variety of industrial inputs. Although quantitative response curves of insect grazers to algal abundance and fish growth to insect production are key to predicting river ecosystem responses to nutrient and contaminant loadings, these empirical relationships are poorly understood. For example, insect grazers have the potential to affect algal production, biomass and turnover rates (P/B ratios), thereby modifying the uptake and transfer of nutrients and contaminants. Moreover, as the dominant prey organism of river-dwelling fish, the secondary production of grazers may limit fish growth rates.

NHRI is investigating the responses of benthic macroinvertebrates in riverine ecosystems along nutrient and contaminant gradients in the Thompson River, British Columbia, a major tributary of the Fraser River and an important river for the salmon fishery. Field and mesocosm studies indicate that effluents have strong impacts on the food web structure of this large river ecosystem. For example, downstream gradients in benthic invertebrate density, biomass and species composition are inversely related to the downstream nutrient and contaminant gradients. Benthic fish are affected similarly. Effluent gradients, thus, provide the environmental template upon which these changes in food web structure are built. However, the research also demonstrates that interspecific biotic interactions (e.g., predation) are very important in determining ecosystem level responses to effluent perturbations. Experiments are currently under way to determine the importance of herbivore-predator interactions as they affect algal biomass accumulation in large rivers. This research program has also developed rapid assessment techniques for establishing the density, biomass and composition of benthic invertebrates and fish in rocky-bottom rivers.

Assessing the potential for herbicide uptake in aquatic invertebrates

The effects of herbicides on different components of aquatic ecosystems remain largely undetermined. Since many of the most commonly used herbicides dissolve in the same solvents that can dissolve fats and oils, an NHRI study is investigating whether the fats used as energy storage molecules by aquatic invertebrates (triacylglycerols) act in a similar manner to common laboratory solvents and have the necessary properties to dissolve and attract these herbicides. In collaboration with Monsanto Agricultural Corporation, Project members used a technique called autoradiography to demonstrate that a radioactively labelled herbicide (triallate) accumulated in some of the tissues of amphipods, a common aquatic invertebrate: the highest and most persistent concentrations of the herbicide being associated with droplets of energy reserve fat adjacent to the gut. Seasonal patterns of these energy reserves in amphipods collected from two different lakes and a eutrophic prairie slough were highest in spring and, to a lesser extent, in the fall suggesting that the potential for uptake of lipid soluble herbicides would be accentuated at these times. This research provides information to help determine how chemical compounds persist in the environment and what factors govern their uptake into aquatic organisms.

PRAIRIE LAKE STUDIES

Interrelationship between nutrients, phytoplankton standing stocks, and zooplankton population dynamics

Prairie lakes are inherently productive systems. They are shallow, located in drainage basins in which the soils are organically-rich, and are affected by a number of climatic and edaphic processes that tend to conserve nutrients such as phosphorus. Moreover, prairie lakes have been perturbed by various anthropogenic events (sewage discharge, runoff from feedlots and agricultural lands), resulting in the increased eutrophication of these lakes: excess algal blooms may be more prevalent now than in pre-European times.

This study aims to understand the processes affecting algal blooms in prairie lakes and the potential usefulness of various remedial actions in their reduction. Work focuses on two prairie lakes - a hypertrophic, hyposaline lake (Humboldt) and a mesotrophic, saline lake (Redberry). In Humboldt Lake, large-bodied zooplankton grazers (Daphnia) are abundant and grazing pressure on the algal community heavy during most of the year. However, because phosphorus levels are high and other conditions favourable, inedible algal biomass accumulates during the summer. In Redberry Lake, zooplankton are apparently less effective in controlling algal biomass because lower primary productivity prevents them becoming as abundant as in Humboldt lake. Moreover, the high salinity is stressful to zooplankton - exhibited in retarded development cycles, smaller body size, and lower fecundity - resulting in reduced abundances of large-bodied zooplankton grazers, a concomitant decrease in zooplankton grazing pressure, and an increase in algal standing stocks.

Microbial processes in nutrient cycles and the fate of pesticides

On the Prairies, saline lakes are interspersed among cultivated fields where both fertilizers and herbicides are frequently used. Herbicide residues and nutrients may accrue to these water bodies through processes of aeolian deposition, surface runoff and groundwater input. This study tested the effects of a herbicide (triallate) and nutrients on various measures of microbial (algal and bacterial) activity and biomass in two prairie saline lakes. To date, microcosm (2-L flasks) experiments using natural microbial assemblages have been completed to test the short-term (1 week) effects of nitrogen, phosphorus and three concentrations of triallate on chlorophyll a (algal biomass), bacterial numbers, activity and production. Preliminary results indicate that triallate significantly decreases chlorophyll a levels but this effect can be partially ameliorated by increased nutrient concentrations. Research will continue to examine triallate and nutrient

effects on bacterial and phytoplankton populations over periods of several weeks. Fate and biodegradation of triallate will also be studied using radiolabelled triallate and natural microbial assemblages.

Impact of high sulphate (salinity) concentrations on phosphorus cycles in prairie saline lakes

Phosphorus models of saline systems with high sulphate concentrations predict the plankton will be P-sufficient. Redberry, a magnesium sulphate-dominated lake in central Saskatchewan, exhibits high levels of orthophosphate with concomitant low levels of chlorophyll a. This apparent anomaly led to an investigation of phosphorus limitation and nutritional fitness of the plankton in this lake and two others of differing salinities and trophic status. Bioassays, ^{32}P-turnover times, alkaline phosphatase activity, and sestonic protein-to-carbohydrate ratios indicated that plankton in all of these systems are phosphorus deficient. Moreover, in two of the lakes, size fractionation of the plankton during ^{32}P-uptake studies indicated that the 0.1 - 1.0 %m, or bacterial, fraction was responsible for 75% of the ^{32}P-uptake. The three lakes studied do not conform, therefore, to the model predicting plankton P-sufficiency based on high sulphate levels.

Aquatic studies in the boreal lakes of Prince Albert National Park

Prince Albert National Park is a relatively pristine ecosystem. Nevertheless, its three largest lakes, Crean, Kingsmere, and Waskesiu, have experienced perturbations due to a commercial fisheries in the 1920s, an ongoing sport fishery, and the construction of a dam on each of the rivers draining these lakes. Studies are being conducted to address various aspects of these issues. The first investigates a continuing low lake-trout population in Crean Lake, despite a moratorium on their fishery. To test the hypothesis that spawning beds have been damaged due to accelerated shoreline erosion occurring after the Crean Lake outflow was dammed, fertilized lake trout eggs (obtained from Kingsmere Lake) were placed in incubators and installed at eight reef sites in Crean Lake. Sedimentation traps were placed at each site allowing for the estimation of gross sedimentation rates and water chemistry (including dissolved oxygen) studies conducted through winter. Results suggest that the spawning beds are in good condition and thus suitable for lake trout egg survival. Predation on lake trout eggs, fry, and other early life history stages may be a primary factor limiting the recovery of the Crean Lake trout population from previous environmental stresses.

Another study continues an environmental assessment of Waskesiu Lake with a special focus on the potential effects of dam removal from its inflow river (Kingsmere) and outflow river (Waskesiu). An intensive littoral zone survey was conducted in July 1992 and seasonal limnological sampling is being conducted at two open-lake stations. Limnological data will be compared with data collected from ongoing studies in the prairie region. Park studies are being conducted with Parks Canada support and with the collaboration and assistance of the Department of Geography (University of Saskatchewan), the United States Fish and Wildlife Service (Ann Arbor), Saskatchewan Department of Parks, Recreation, and Fisheries, and the Prince Albert Diving Club.

The influence of the Slave River on Great Slave Lake

Relatively little is known about the limnological features of the large lakes (Athabasca, Great Slave Lake, and Great Bear Lake) located in the Northern Rivers Basin. Great Slave Lake, at the headwaters of the Mackenzie River, receives most of its inflow from the combined drainage (via the Slave River) of the Peace and Athabasca Rivers. This study is investigating the basic limnological features of Great Slave Lake with a focus on the influence of the Slave River on this ecosystem. With Department of Indian and Northern Affairs support, a series of core samples were collected in March 1992 from the western basin (influenced by the Slave River) and the eastern arm (minimally influenced by the Slave River) to determine the concentration of organic contaminants in the sediments, sedimentation rates, and organic contaminant deposition rates. Water column studies were conducted to obtain information about suspended solids, dissolved oxygen concentrations, plant nutrients, bacterial abundance, algal biomass and composition, and zooplankton abundance and composition. The Great Lakes Environmental Research Laboratory (U. S. National Oceanic and Atmospheric Administration) is collaborating in this study as part of its developing initiative on comparative studies of large lakes of the world.

UV-B - aquatic ecosystem impacts

Some consequences of elevated UV-B light on the earth, such as an increased incidence of skin cancer in humans, are already known, but the effects on the ecology of aquatic ecosystems are not yet understood. Because UV-light is attenuated in water, its ecological impacts might be stronger in shallower streams and rivers. As part of NHRI's research program on the environmental effects of long-term global change, a study to monitor river biota for the effects of UV-light has begun. During 1992, an experiment at Environment Canada's Experimental Troughs Research Apparatus (EXTRA) measured levels of UVB and

UVA light over the summer and correlated them with the amount of visible radiation and total column ozone. Results confirmed that UV-light inhibits the growth of attached algae. However, under the influence of UV-radiation, species succession occurs to algal taxa that appear to be more tolerant of UV-light, a succession that may alter long-term impacts. The process of microbial colonization, growth and succession to steady-state biomass conditions was documented by time-lapse video. Samples to confirm algal biochemical and pigmentation adaptation to UV light were collected and analyzed.

Ecotoxicology and dynamics of a wetland invertebrate food web

Prairie wetlands are complex ecosystems, supporting a rich and abundant flora and fauna. This biodiversity is increasingly threatened by environmental stresses such as herbicide/pesticide use and other agriculture-related disturbances, the ecological effects of which are not fully understood. NHRI scientists have begun a long-term programme to develop a toxic bioassay system to assess the chronic and acute effects of chemical contaminants in wetland ecosystems and provide the scientific information needed to ensure wetland sustainability.

INTERNATIONAL ACTIVITIES

Microbial ecology of the Eastern Mediterranean Sea

The Eastern Mediterranean Sea is one of the world's pristine marine ecosystems, comparable to the Sargasso Sea. However, industrial and municipal effluents are discharged to the Eastern Mediterranean from bordering countries: for example, the Bahr el Baqar canal carries waste leachate from Cairo's (15 million people) municipal waste centre to Lake Manzala and the Eastern Mediterranean. A six nation (Israel, Turkey, Greece, Yugoslavia, Italy, U.S.A.) consortium was formed a few years ago to examine the physical oceanography of the Eastern Mediterranean (POEM). POEM II, consisting of members from the same countries and scientists from NHRI, re-examined the physical features of the Eastern Mediterranean and for the first time included chemical and biological (microbial) measurements. This was done to gain more knowledge of this marine ecosystem in order to try to predict the impact of development and population growth in the bordering countries, and to determine how such a pristine system is capable of supporting the commercial fisheries based in the bordering countries.

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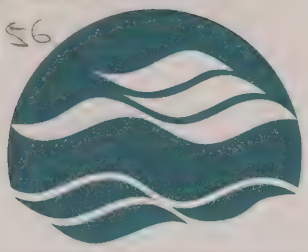
Aquatic Ecosystems in Semi-arid Regions: Implications for Resource Management. Proceedings of NHRI Symposium No.7, August 1990, Saskatoon, SK. 375p.

Editors: R.D. Robarts and M.L. Bothwell

Jointly published by NHRI and the Rawson Academy of Aquatic Science, this book contains both contributed and invited papers presented at an international conference on aquatic ecosystems held in Saskatoon in 1990. It covers a wide range of topics including the aquatic ecology of lakes, rivers, and wetlands, the chemistry of surface and ground waters, the impact of toxic contaminants on the biology of aquatic ecosystems, and water management strategies and techniques. The book is aimed at water managers in government and industry, graduate students, university researchers and professors, and aquatic scientists with particular interests in managing water resources in semi-arid regions, such as northern and western Canada.



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Northern Hydrology: Selected Perspectives. 1991. Proceedings of the Northern Hydrology Symposium. NHRI Symposium No. 6, 545 p. ISSN 0838-1984, ISBN 0-662-18742-3, Cat. En36-512/6E. $28.00 plus S&H of $3.00 CDN, $6.00 US, $7.00 INT'L.

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Proceedings of the Conference on Aquatic Ecosystems in Semi-Arid Regions: Implications for Resource Management. 1992. NHRI Symposium No. 7, 386 p. ISSN 0838-1984, ISBN 0-662-19029-7, Cat. En36-512/7E. Soft cover $15.00 plus S&H of $4.00 CDN, 4.00 US, 7.00 INT'L. Hard cover $25.00 plus S&H of $4.00 CDN, $4.00 US, $7.00 INT'L.

Proceedings of the Workshop on Using Hydrometric Data to Detect and Monitor Climatic Change. 1992. NHRI Symposium No. 8, 255 p. ISSN 0838-1984, ISBN 0-660-14564-2, Cat. En36-512/8E. $23.00 plus S&H of $4.00 CDN, $4.00 US, $7.00 INT'L.

Proceedings of the Workshop on Soil Moisture: Modelling and Monitoring for Regional Planning. 1992. NHRI Symposium No. 9, 211 p. ISSN 0838-1984, ISBN 0-660-14744-0, Cat. En36-512/9E. $22.00 plus S&H of $3.00 CDN, $3.00 US, $4.00 INT'L.

Environmental Aspects of River Ice. 1993. NHRI Science Report No. 5, 169 p. ISSN 0843-9052, ISBN 0-662-20820-X, Cat. En36-513/5E. $20.00 plus S&H of $3.00 CDN, $3.00 US, $4.00 INT'L.

Proceedings of the Ninth International Northern Research Basins Symposium/Workshop. 1993. NHRI Symposium No. 10. Volume No. 1, 467 p. Volume No. 2, 466 p. ISSN 0838-1984, ISBN 0-660-14765-3, Cat. En36-512/10E. $40.00/set plus S&H of $3.00 CDN, $6.00 US, $7.00 INT'L.

FREE PUBLICATIONS

Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada. 1988. NHRI Symposium No. 1, 502 p. ISSN 0838-1984, ISBN 0-662-16017-7, Cat. En36-512/1E.

Proceedings of the Prairie Drought Workshop. 1988. NHRI Symposium No. 2, 359 p. ISSN 0838-1984, ISBN 0-662-56788-9, Cat. En36-512/2E.

Working Group on River Ice Jams: Field Studies and Research Needs. 1990. NHRI Science Report No. 2, 121 p. ISSN 0843-9052, ISBN 0-662-17566-2, Cat. En36-513/2E.

Proceedings of the Workshop on Applications of Remote Sensing in Hydrology. 1990. NHRI Symposium No. 5, 386 p. ISSN 0838-1984, ISBN 0-662-17687-1, Cat. En36-512/5E.

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The National Hydrology Research Centre conducts research on issues relevant to the sound management of Canada's aquatic resources. These include the detection and prediction of climatic change, nutrients and toxics in surface and ground waters, environmental impacts on northern systems, and the integrity and health of aquatic ecosystems. In collaboration with national and international partners, NHRC scientists participate in interdisciplinary research programmes designed to address regional, national and international environmental problems.

NATIONAL HYDROLOGY RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE EN HYDROLOGIE

Process Modelling Project

Report on Recent Activities

1992 - 93

Primary goals

- to design models capable of accurate simulation of hydrological processes
- to develop tools to investigate the effects of climatic change on water resources

Scientists in the Process Modelling Project use satellite images and geographic databases such as digital elevation models and land-cover maps to design accurate models that can help elucidate hydrological processes and assist in the effective management of water resources. Their research involves conducting process studies in the field, developing algorithms for use of remotely-sensed data, and developing and testing of models. They work with governments, international agencies such as the Canadian International Develoment Agency and UNESCO, utilities, universities, and the private sector. Recent activities include research studies in prairie and mountain environments.

Mountain streamflow measurement

Accurate measurement of the discharge of fast-flowing mountain streams is important for hydropower, glaciological mass-balance studies, and water supply estimation. The normal use of current meters is inaccurate in mountain streams where the slope and velocity are usually high and the bed is irregular. The alternative technique, using dilution methods, is usually restricted to special purpose or research measurements because of the need to mix chemical solutions in the field and to make tedious measurements and calculations.

Equipment developed at NHRI, in conjunction with field work in the Rocky Mountains, has produced a method of automating these measurements and computations, allowing for wider application of the technique and resulting in better data for flows in mountain streams. The next step in this study will be to try the method under ice conditions. The existing techniques are extremely inaccurate and it is possible that the conductivity method could be used to increase the accuracy of such measurements.

WATERSHED MODELLING

Watershed models are used by researchers to test our understanding of precipitation-runoff processes and by operational agencies to simulate streamflow for water supply, hydropower development, and other related uses. Such models are playing an increasingly important role in the investigation of climatic change scenarios.

The SLURP model

The SLURP model is designed to use satellite data. Work by a Co-op student this year concentrated on using passive microwave data to estimate snow water equivalent. It became evident that the satellite data gave better estimates of runoff than the data from snowcourses. The model has also been used this year to develop methods of incorporating data from the Canadian General Circulation Model(GCM) for 1 x CO_2 and 2 x CO_2 scenarios for the Kootenay Basin in the Rocky Mountains. SLURP can do this because the parameters are related to land-use information derived from Landsat images. The model was applied to the outputs from the Canadian GCM over the Mackenzie Basin to investigate the runoff component of the GCM output and to gain information about the relative importance of different processes in large-scale northern basins. It was found that the model was able to correct inadequacies in the land phase component of the GCM. Financial support has been provided for the study by Manitoba Hydro, B.C. Hydro, DIAND, and GEWEX.

Hierarchical hydrological model

In a cooperative project with the University of Waterloo, the SLURP model will be developed as one component of

a hierarchy of hydrologic models (HHM) operating at different scales and able to interact with General Circulation Models (GCMs). Development of such an HHM will provide a tool to improve the hydrologic input to GCMs and to interpret the output from them, as well as to answer questions about continental-scale hydrology under changing circumstances.

HYDROTEL

Project scientists are working on CANFLOW, the name given to the corrected version of the HYDROTEL watershed model developed by INRS-Eau, University of Quebec for Environment Canada. The model is made up of three parts: the hydrological model itself, an image analysis system to provide data from satellite images called Imatel, and a component to analyze the watershed physiography called Physitel. Work continues to correct the existing model and its associated components and develop them into a working package. Additional financial support for this work comes from the Canadian Centre for Remote Sensing.

Time series analysis

Many studies of the impacts of climatic change assume there is good evidence of such changes actually occurring. However, examination of many data fail to show any such changes. This study is developing the necessary techniques for time series analysis and is investigating temperature, precipitation and streamflow data from Canadian stations as well as data from large lakes in North America and Africa to facilitate detection of the effects of climatic change.

Evapotranspiration in a prairie environment

NHRI is assessing existing techniques and developing new approaches for modelling evapotranspiration. The Complementary Relationship Areal Evapotranspiration model (CRAE) is being tested within the framework of the World Meteorological Organization's project on the Evaluation of Methods for Estimating Areal Evapotranspiration. Work proceeds in collaboration with scientists at the University of Saskatchewan on the assessment of a new approach to estimation of evapotranspiration, one that relies on the development of a general evaporation equation and has the advantage of requiring no prior calculation of potential evaporation.

A new algorithm has been developed for the use of remotely-sensed surface temperature data in evapotranspiration estimation. The method depends on the feedback relationships between the surface and the overpassing air layer. Field studies have shown that the relationship is applicable to a variety of surfaces: e.g., bare soil, growing wheat, grass, irrigated barley and a closed aspen canopy. In a collaborative project with the Atmospheric Environment Service, the algorithm will now be tested on a wider range of surfaces under varying climatic conditions. This new approach allows for the use of remotely-sensed data within conventional evapotranspiration models.

Open water evaporation

Evaporation from open water is an important component of the water budget in semi-arid regions of the prairies. The rate of evaporation is known to increase with the wind and is often modelled as a linear function of wind speed. The accuracy of this wind function and the effect of spray generated by breaking waves at higher wind speeds remain uncertain in a prairie environment. Recent oceanographic studies contradict earlier laboratory results and suggest that the evaporation coefficient is independent of spray generation at high wind speed. Spray may be important during the open water season on the prairies, however, because of the large advection of sensible heat.

In 1991, NHRI began a study on the effects of wind speed, spray from breaking waves, atmospheric stability, and the advection of sensible heat on evaporation. Experiments were conducted throughout the summer in a large shallow lake, Quill Lake, Saskatchewan. The lake is surrounded by grain fields, that are very flat with few trees. Net radiation, wind velocity, air temperature, humidity, water temperature at 5 depths and sediment temperature at 3 depths were measured at 2 minute intervals from a platform in the lake. Vertical profiles of wind velocity, air temperature and humidity were made at 10 minute intervals simultaneously at the upwind edge and at the lee shore of Quill Lake during high wind conditions. Eddy correlation measurements of evaporation and sensible heat flux were made simultaneously at the lee shore.

Results of these experiments have been presented at several national and international conferences, and will be of value to HEATMEX 93 (Heat, Evaporation and Transfer of Mass Experiment), an experiment conducted in collaboration with the National Water Research Institute that addresses the same overall objectives.

Microwave satellite snowpack monitoring

Forecasting spring runoff requires monitoring of winter snowpack. Using eight years of archived Nimbus 7 satellite observations, the potential for microwave remote-sensing of snow is under investigation. The multi-temporal relation between snowpack and microwave emission was derived for each of eight winter periods, for three Plains target areas. A set of electromagnetic models is being developed for testing and image interpretation. Programmed for testing

on a PC 486 computer, the multiple scattering model RADFIT was designed for simulation of snowpack microwave time series, incorporating multiple layers, mixed pixels, and atmospheric absorption. Statistical scatter in the snowpack correlations for the winter 1984-5 was diagnosed with the model. Work in progress includes model upgrading to include dense scattering media and multiple atmospheric layers: snowpack correlation testing for all multi-temporal data sets for the Plains targets: and snowpack correlation testing for monthly mean data sets for twenty-three Canadian watersheds in five different regions.

Radar satellite snowmelt detection

The timing of spring runoff from mountain basins requires detection of snowmelt from different slopes and elevation bands of the watershed. High resolution all-weather observations are now available from the ERS-1 radar satellite, launched in July 1991. Project staff instrumented an alpine snowplot in Brewster Creek basin, in the Rocky Mountains near Banff, and deployed a radar beacon for calibration. Bi-monthly images were obtained from April 1992 to the present. Multi-temporal analysis demonstrated that snowmelt can be detected with C-band radar in unforested areas such as the alpine, talus cones, avalanche tracks, and meadows. Both the onset of wet snow conditions and the disappearance of the snowpack were identified as functions of elevation, slope, and aspect. A mountain target radar-return catalogue has been assembled and reported at the Canadian Centre for Remote Sensing Radar Data Development Program Workshop in Gananoque, Ontario.

Other activities

During this fiscal year, an image analysis and geographic information system was installed at the National Hydrology Reserch Centre as a central facility to support ecosystem and environmental research. The Centre has two PCI EASI/PACE image analysis systems and two SPANS geographic information system as well as many other software packages for analysis of spatial data.

A successful workshop on the use of hydrometric data to detect and monitor climatic change was held at NHRI: the proceedings are now available.

The project leader acted as a consultant for two international agencies, the Canadian International Development Agency and the International Development Research Centre, to provide expertise on hydrological modelling of the Nile and the Indus basins.

Using Hydrometric Data to Detect and Monitor Climatic Change: Proceedings of NHRI Symposium No.8, April 1992, Saskatoon, SK. 247p.

Editors: G.W. Kite and K.D. Harvey

Climatic change is one of the most pressing environmental issues of today. Canada's Green Plan lists some of the possible effects of global warming on Canadian water resources, including a significant decline in water supplies to southern areas, changes in fish populations, increases in soil degradation and erosion, and changes in rainfall patterns.

Given that the effects of climatic change on aquatic ecosystems could be profound, a significant increase in the research effort on water-related issues is indicated. This collection of papers presents up-to-the-minute information on the use of hydrometric data in detecting and monitoring climatic change. Topics include the relationships between climate change and glaciers, ice-cores, groundwater, organic carbon fluxes, various meterological variables, and streamflows. The publication also includes detailed papers on statistical analysis as well as extensive discussion on the development of a hydrometric network to detect and monitor climatic change

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Selected Publications

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Groundwater and Contaminants Project

Report on Recent Activities

1992 - 93

Primary goals

- to gain greater knowledge about the behaviour of contaminants in groundwater systems
- to develop methods to prevent pollution migration
- to investigate techniques to remediate contaminated areas

The Groundwater and Contaminants Project addresses these groundwater issues in regional, national, and international contexts through cooperative research studies conducted at locations in western and northern Canada, and through collaboration with scientists from other countries. As well as carrying out an extensive programme of research in the field, NHRI groundwater scientists conduct a series of studies using a mesoscale model in the laboratory at the National Hydrology Research Centre. Details of research results and recent activities are given for each study in the Project.

Contaminant transport in the Condie aquifer

In cooperation with the University of Waterloo and the Saskatchewan Research Council, NHRI groundwater specialists are studying a very long and narrow contaminant "plume" in the Condie Aquifer, near Regina, Saskatchewan. Using numerous multilevel piezometers, detailed measurements of the geometry of the plume have been completed. The field data and numerical simulation show there is extremely little spreading of the plume by lateral dispersion, apparently because the flow in the aquifer is very steady and the aquifer consists of a uniform coarse sand. Such minimal spreading has been documented for plumes of a few hundred metres length, but has not previously been encountered for longer plumes. Low rates of sideways dispersion have important implications for the prediction and monitoring of groundwater contaminant movement. In this case, for example, the plume passed undetected between several monitoring wells and affected the water quality in a production well 8 kilometres distant. A detailed report has been prepared and papers are in preparation.

Groundwater contamination by potash mine brines

There are ten potash mines in Saskatchewan, each with a large salt tailings and brine storage area. With funding from the Saskatchewan Potash Producers Association, an NHRI study is under way, in conjunction with the Saskatchewan Research Council, to determine how the brine is moving down through the clays and tills below these waste storage areas and to ascertain what the eventual impact on underlying aquifers may be. Detailed data have been obtained on the downward penetration of brine at most of the mine sites, and results are now being analyzed by means of numerical models for flow and transport of dense fluids (i.e. brine) in fractured porous media. Further work will concentrate on whether and how the underlying aquifers are likely to be affected over a time scale of hundreds of years.

Solute transport in low-permeability tills and clays

Some of the thick clayey tills and clays in Plains regions have very low permeability, and transport of natural solutes and contaminants through them may be extremely slow. Such slow movement would imply that recharge to underlying aquifers is very limited, but would also suggest that these tills and clays may have excellent properties for isolation of wastes. As part of a cooperative study with the University of Waterloo, extensive data on solute transport have been collected from several typical sites and are now being analyzed by means of numerical models. The results obtained to date suggest that movement of solutes within

the tills and clays is even slower than expected and indicate that waste isolation for thousands of years may be feasible by taking advantage of the unique hydrogeological properties of these formations.

Research under the Canada/Germany Science and Technology Agreement

Collaboration between government agencies, universities and private industry is becoming an essential aspect of modern multidisciplinary research. To bring together expertise on aspects of biorestoration of organic contaminants and groundwater microbiology and promote the exchange of researchers between both countries, NHRI groundwater scientists have undertaken a collaborative venture with German counterparts under the Canada/Germany Agreement. As part of the venture, in 1992 NHRI hosted a workshop on Sulphur Transformations in Soil Ecosystems, attended by an equal number of sulphur researchers from Germany and Canada. Researchers presented papers on their current findings and developed new collaborative research projects on sulphur transformations in the subsurface.

Organic mass spectrometry laboratory

Green Plan Lab Revitalization funding made possible the recent purchase of advanced GC/MS/MS and GC/MS instrumentation (VG AUTOSPECQ and VG TRIO 1000) to provide sophisticated analytical support for NHRI research. With this equipment available, the Groundwater Project obtained approval for PERD (Panel on Energy Research and Development) funding of a major research project to support technology development in the private sector. The mass spectrometry instrumentation is now set up and supporting a number of national and international studies. Research includes international projects with the University of Wales and Komex International,and national projects supporting students at the University of Saskatchewan. These studies alone include the research of two Ph.D students, two M.Sc. students, a visiting scientist from the National Research Council, one research scientist and one senior technician.

Acid mine drainage

Concerns about the impacts of acid-generating mine waste are shared by researchers, regulatory agencies and mine operators. To gain knowledge to facilitate more efficient prediction, prevention, treatment and control of acid mine drainage, NHRI's research has focused on the water-rock interactions involved in the acid generation and metal leaching processes.

At the abandoned Mount Washington mine site on Vancouver Island, British Columbia, continuing investigation has clarified the acid generation and metal leaching mechanisms. As shallow bedrock in the remnant open-pit still contains much sulphide and fracture-controlled groundwater flow plays a significant role in the acid generation process, a conventional water diversion scheme is unlikely to arrest the production of acidic drainage. The acid and metal attenuation capacity of a natural wetland system adjacent to the open-pit has been demonstrated, however, and an integrated abatement strategy is deemed more appropriate for the site.

Other work includes a study entitled "Prediction and prevention of acid rock drainage from a geological and mineralogical perspective" conducted under the Mine Environment Neutral Drainage (MEND) program, in which seven common metallic ore types were ranked according to their acid rock drainage (ARD) potential, and a collaborative study with Indian and Northern Affairs of "Natural acid rock drainage at Macmillan Pass, Yukon," also partially funded by MEND. Reports on both these studies are in preparation.

Formation of *in situ* microbial barriers for remediation and containment of groundwaters at contaminated sites

Control of contaminant movement to prevent further environmental contamination and facilitate degradation/treatment is an essential component of any remediation program. Existing treatment approaches have proven effective in some cases, but each has certain disadvantages. Alternative technology is required, therefore, for effective treatment and control of the broad range of contaminants in groundwater. NHRI is currently researching biotechnological approaches, both for containment of contaminants and clean-up or remediation of contaminated sites.

In the process of creating a microbial barrier starved cells are injected into the formation and when followed with a nutrient solution they grow, reproduce and produce exopolysaccharide creating a plug. These *in situ* microbiological barriers may be used to (1) create barriers/aquitards in porous aquifer materials to reduce flow rates, (2) increase the efficiency of standard pump and treat approaches, (3) concentrate and immobilize toxic compounds (e.g., metals, organics) through interaction with cells and exopolymer, and (4) facilitate natural or biostimulated degradation *in situ*. Results of initial studies indicate that the barriers can reduce the hydraulic conductivity of porous material by a factor of 100X, and that the barriers are resilient self-sealing structures.

Mesoscale model aquifer studies

Although herbicides are typically applied to the crop and weed canopy, substantial quantities of the active ingredient penetrate to the soil surface. For example, up to 90% of foliar applications may contact the soil surface or be subsequently incorporated into soils. Leaching of these compounds has not, in general, been considered an important factor in their environmental chemodynamics. However, many herbicides or their metabolites can be mobile particularly under conditions of increasing sand content, water application rate and decreasing pH . The frequent detection of agrochemicals in groundwaters and their toxic nature have resulted in increasing public and regulatory concern regarding impacts on drinking water supplies and led to an increased demand for research on and monitoring of these chemicals.

During the evaluation of the environmental fate of agrochemicals it is desirable to combine natural conditions representative of the field with well controlled and/or monitored conditions typical of the laboratory. Evaluation of leaching potential for agrochemicals has followed either laboratory or field testing approaches, however, and rarely combined the two. Mesoscale models (2.4 m dia. X 4.6 m high and 65 tonnes) were developed to provide an optimum environment for monitoring the fate and mobility of agrochemicals with conditions approaching those of natural field sites, yet near steady-state with regard to physical and chemical conditions. Studies to date indicate that the mesoscale model exhibited physical, chemical and biological gradients and levels that were similar to many field sites. In addition, the system does have the suggested advantages of controlled fluxes, intensive sampling and instrumentation, high microbial diversity in a largely unaltered environment, and controlled, environmentally acceptable experimentation.

Geochemistry of glacial deposits

Hydrochemical patterns in groundwaters from permeable and slowly permeable glacial deposits yield detailed information on hydrologic settings and on processes such as transport of contaminants and salinization of soils. Understanding the relationship of groundwater and soil salinity is vital to maintaining a sustainable agriculture-based economy on the Prairies.

As the majority of prairie groundwaters and saline soils are dominated by sulfate, sulphur dynamics deserve special attention. Using applied chemical and isotope techniques, the sources and dynamics of sulphur in the "weathered" zone (10 m below ground) and in saline soils at 5 sites in the Prairies of western Canada were examined and the major source of sulfate determined to be oxidation of pyrite in glacial tills. Variation in the abundance of sulfate in shallow groundwater was found to be directly related to the local hydrologic setting.

ABBOTSFORD AQUIFER

1,2-Dichloropropane monitoring

In 1990/91, the Institute began a detailed study to determine the factors controlling the migration and fate of 1,2-dichloropropane in the Abbotsford aquifer. Low but persistent levels of this contaminant have been measured at selected locations within the aquifer due to past usage of soil fumigants containing 1,2-dichloropropane for the control of nematodes in raspberries. The study is being conducted jointly with the regional office of the Inland Waters Directorate in Vancouver and the Agassiz and Vancouver Research Stations of Agriculture Canada. Regular semi-monthly monitoring for selected parameters was initiated in July, 1991 at piezometer sites throughout the saturated zones of the aquifer to determine the time dependence of these constituents. Monitoring continued in 1992 and results are being analyzed and published.

Nitrate contamination

Nitrate contamination of unconsolidated surficial sand and gravel aquifers has been identified as a significant environmental problem in the Fraser Lowlands of British Columbia, and is believed to stem from long term agricultural practices, such as poultry manure stockpiling and the application of fertilizers. The contribution of domestic septic effluents to nitrate contamination is not known, but could be an important contributor. In 1992/93, NHRI began a stable isotope study of nitrates in the Abbotsford aquifer. The objectives of this study are to characterize isotopically nitrate in the aquifer, as well as potential nitrate sources (manure, fertilizer, sewage). The stable isotope data will be used to establish the relative magnitude of each of the potential contaminant sources, and to ascertain whether denitrification (natural remediation) occurs in the aquifer. Information regarding the controls on denitrification is essential in order to predict the ability of the aquifer matrix to sustain natural remediation of nitrates in the future.

Humic substances in groundwater

High concentrations of high molecular weight aquatic humic substances (HS) are found in a number of Canadian groundwater systems. In drinking and treated water supplies, they have been linked to chloroform and methane production, poor water quality, odour, fouling, and high iron concentrations. Other research has shown that HS facilitate heavy metal and radionuclide transport in the subsurface. Little is known about their toxicity in drinking

water to humans, nor is their origin and transport in groundwater well understood. Isotopic and detailed geochemical characterizations of HS in groundwater provide a powerful tool to distinguish between recent and fossil sources, and aid in understanding the transport and potential mechanisms and processes responsible for humification of groundwater.

NHRI is currently conducting independent and collaborative HS research projects with the University of Waterloo and the Technical University of Denmark in Copenhagen to investigate a number of aquifers and aquitards containing variable HS concentrations. In Canada these include the Alliston regional aquifer (Ontario), the Milk River aquifer (Alberta), and clay till aquitards (Saskatchewan, Alberta), among others. In Denmark they include the Skagen and Tues Naes unconfined aquifers. The research will aid in establishing further guidelines for acceptable levels of humic substances in groundwater, beyond which unacceptable taste, metals, fouling, and trihalomethanes become problematic.

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Selected Publications

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